LCA Case Studies

Cradle-to-Gate Study of Red Clay for Use in the Ceramic Industry

María-Dolores Bovea[1]*, Úrsula Saura[1], Jose Luis Ferrero[2] and Josep Giner[3]

[1] Department of Mechanical Engineering and Construction, Universitat Jaume I, Av. Sos Baynat s/n, 12071 Castellón, Spain
[2] WBB-Spain, C/ Ruiz Zorrilla 1, 6, 12001 Castellón, Spain
[3] ReMa-Medio Ambiente, S.L., C/ Crevillente, 1, entlo., 12005 Castellón, Spain

* **Corresponding author** (bovea@emc.uji.es)

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Abstract

Background, Goal and Scope. The ceramic tile industry is one of the most important industries in Spain, with the highest concentration of firms to be found in the province of Castellón on the Mediterranean coast. The basic input material for this industry is red clay. The aim of this study was to carry out an LCA of the process of mining, treating and marketing this clay in order to identify the stages and unit processes that have the greatest impact on the environment.

This LCA examines all the stages of the red clay from cradle to the customer's gate, including the process of mining and treating the clay in the mining facilities and its later distribution to end users.

Methods. Life cycle inventory (LCI): An exhaustive LCI was performed by collecting data from the mine run by Watts Blake Bearne Spain, S.A. (WBB-Spain) in Castellón. Inputs and outputs were collected for all the unit processes involved in the mining, treatment and marketing of the clay:

- Mining the clay, which embraces the unit processes of removing the layer of vegetation covering the chosen area, preparing the area to allow access for the firm's vehicles, and boring or blasting the place the clay is to be extracted from.
- Treating the clay that is mined to make the finished product, which entails all unit processes required to separate out the waste material and transport it to the tip (which will later be reconditioned), excavating and transporting the clay to the crushing plant and later storing it in heaps before delivery to customers. All the internal transport that takes place between each unit process has also considered.
- Distribution of the final product, where the clay is loaded onto dumper trucks and delivered to the customer.

Life cycle impact assessment (LCIA): According to ISO 1404X standards, the LCIA is performed at two levels. Firstly, the emissions accounted for in the inventory stage are sorted into impact categories to obtain an indicator for each category (mandatory elements). Secondly, the weighting of environmental data to a single unit is applied (optional elements). In compliance with ISO 14042, a sensitivity analysis is performed and three different impact assessment methods (Eco-Indicator'95, Eco-Indicator'99 and EPS'2000) are applied in order to analyse their influence on the results.

Results. The processes that involve the movement of clay within the mine (excavation and loading and transport to the crushing facilities and heaps) are the ones that make the greatest contribution to impact categories for pollutant emissions. As weighting methods in LCA remain a controversial issue, a recommendation when robust results are required, can be to use several methods to examine the sensitivity of the results to different values and worldviews. In our application case, in spite of the differences between the three impact assessment methods applied (Eco-Indicator'95, Eco-Indicator'99 and EPS'2000), the same conclusions can be established from the environmental point of view and we can conclude that the ultimate results are not sensitive in the transformation of mid-points to end-points.

Discussion. Taking into account the characteristics of the product being analysed, in addition to the impact categories for pollutant emissions that are traditionally considered in LCA studies, environmental parameters related to resource use (fuel, electricity and water consumption), waste generation (dangerous and non-dangerous wastes) and land use (natural resource appreciation and land use efficiency) and its later rehabilitation (degree of rehabilitation) have been defined. These parameters can be used as additional criteria for an environmental product declaration or criteria for a future eco-labelling of red clay.

Conclusion. The results of this study made it possible to identify the unit processes that make the greatest contribution to environmental impact that being, specifically, excavation and loading and transport to the crushing facilities and heaps. Such processes are directly related to the fuel consumption, category that faithfully reproduces the environmental profile of most of the impact categories related to pollution emissions. Special interest has the consideration of additional parameters to quantify the land use and its later rehabilitation.

Recommendations. The ceramic tile industry has a basis to market and promote tile products with improved environmental impacts. Given that transport and extraction are dominant underlying issues, it is quite likely that such environmental improvements are also win-win in the economic sense. The availability of exhaustive life cycle inventories is the key to allow this industry to, rapidly, incorporate LCA during product development. Complimentary life cycle costings would also be relatively minimal in terms of effort.

Perspectives. Although this study performs the LCI for the basic raw material (clay), future studies should be conducted to complete an LCI for the remaining elements employed by the ceramic tile industry, with the aim of developing a characteristic LCI database for this industry. This includes data on raw materials (feldspar, silicious and feldspars sand, boron, glaze, frit, etc.) and processes (enamelling, firing, water waste treatment, etc.).

Keywords: Ceramics industry; impact assessment; LCI; mining; red clay; sensitivity analysis

Introduction

Council Directive 89/106/EEC (1989) relating to construction products includes the study of environmental aspects as a requisite to be taken into account in the building sector. Since then, concern for the impact that construction products may have on the environment has grown notably to the extent that nowadays it is generally agreed that the environmental behaviour of these products needs to be improved and that information about such behaviour must be gathered and made public. To this end, the Green Paper on Integrated Product Policy (2001) proposes the use of systems for assessing the environmental behaviour of products that take into account their life cycle (from the mining of the raw materials to the management of waste, bearing in mind the intermediate stages of production, distribution and utilisation). Application of the Life Cycle Assessment (LCA) (ISO 14040 1997) methodology is undoubtedly the ideal framework in which to achieve this objective.

The purpose of this paper is to carry out a cradle-to-gate study of the process of mining, treating and marketing red clay in order to identify the stages of the life cycle and unit processes that have the greatest impact on the environment. This study examines all the stages of the red clay from the clay cradle to the customer's gate, including the process of mining and treating the clay in the mining facilities and its later distribution to end users (the tile manufacturer). As data availability and data quality remain critical factors for successful LCA work (Hischier 2001), special attention will be paid to the process of obtaining field data for the life cycle inventory of the clay.

Red clay is the basic raw material for manufacturing ceramic tiles, the most commonly floor covering used in Spain. Although in the literature it is possible to find different studies regarding the comparison of the environmental behaviour among different materials used as a floor covering such as linoleum, high density laminates, vinyl, carpet, etc. (Gorree et al. 2000, Sjöberg et al. 1997, Günther and Langowsky 1997, Pooting and Blok 1995), there is very few available information regarding the environmental behaviour of ceramic tiles, and thus regarding its main raw material. It is important to highlight the comparison made by Nicoletti et al. (2002) between ceramic and marble tiles, that includes life cycle inventory information of these two materials, however, detailed information regarding red clay is not described.

1 Description of the Process of Mining, Treating and Marketing Clays

The process of mining, treating and marketing clays for the ceramic industry carried out in the Arcitras Mine nº 2112 located in Sant Joan de Moró (Castellón, Spain) and run by Watts Blake Bearne Spain, S.A. (WBB-Spain) (from now, Moró Mine) involves the phases and unit processes shown in **Fig. 1**.

The phase of mining raw materials consists in removing the layer of vegetation (process 1) and preparing approaches to

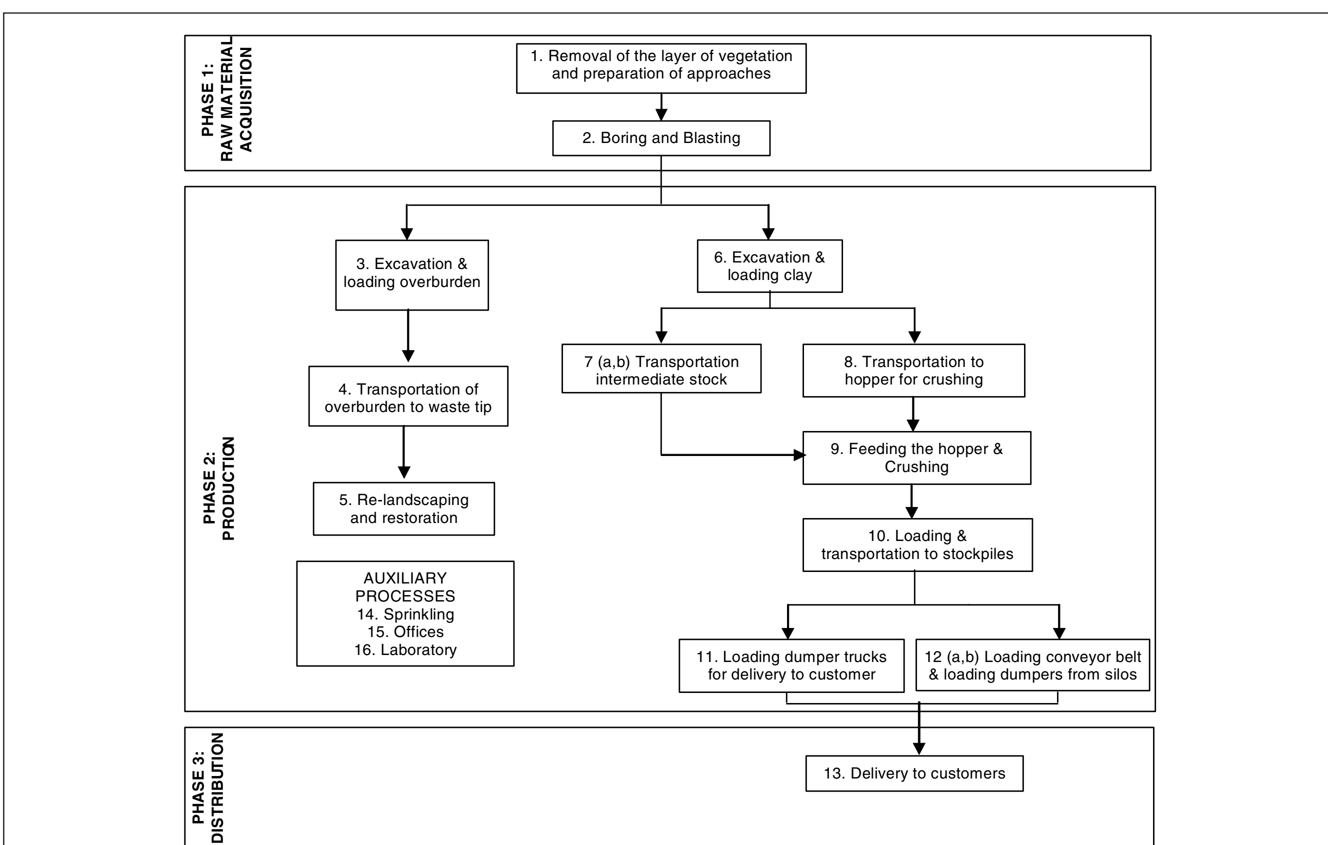


Fig. 1: Flowchart of the process of mining, treating and marketing clays

allow the heavy mining machinery to access the area. Boreholes are then sunk for the explosives and blasting is carried out (process 2), which thus gives rise to an open mine face.

The material that is mined can be divided into barren material, or overburden, (material that is extracted but which has a composition that makes it unfit for sale as clay) and clay (material that will later be treated and marketed as clay). So, the only product obtained from the process is the clay, since the overburden cannot be considered as a co-product but a waste that is used in the land restoration stage.

The overburden is separated out from the clay (process 3) and taken to the waste tip or the backfill area of the mine (process 4). Finally, the area the clay was mined from is re-landscaped and restored to its original layout (process 5).

The clay that is considered fit for marketing is loaded (process 6) and taken directly to the hopper (process 8) for crushing or is stored as intermediate stock (process 7), depending on the market requirements. The hopper is fed with clay which is crushed (process 9) and later extracted with a uniform grain size to meet the customers' needs. Finally it is heaped in stockpiles (process 10) and from there it is loaded directly onto the dumper trucks that will deliver it to the customer (process 11). On certain occasions (mainly when it rains and it becomes impossible to work directly from the stockpiles), the clay is loaded onto a conveyor belt that drops it into a silo, and from there it is loaded straight onto the dumper trucks (process 12). The last stage involves delivering the clay to the end users (process 13).

Ancillary processes such as sprinkling all the work areas and tracks or approaches to the mine with water to prevent the formation of dust (process 14) and the work carried out in offices (process 15) and laboratories (process 16) were also taken into account.

2 Definition of Goal and Scope

2.1 Definition of objectives

The aim of this study was to conduct an LCA of the process of mining, treating and marketing the clay from the Moró Mine which will later be used as an input material in the ceramic industry.

This LCA examines all the stages from the clay cradle to the customer's gate, including the entire process of mining and treating the clay in the mining facilities and its later distribution to end users (i.e. the ceramic industry).

The ultimate purpose of this study is to identify:

- The stages of the life cycle of mining and treating the clay that have the greatest impact on the environment.
- The sub-processes of clay production that have the most important effects on the environment.

At the same time, the intention is to use this LCA, with an appended peer review, as mandated by the ISO guideline though not included in the present publications, as the basis to obtain the Environmental Product Declaration, EPD, (ISO/TR 14025 2000) for this clay.

2.2 Definition of the scope

All the raw materials used in the processes listed in Fig. 1 and their transportation from each of the suppliers were taken into account in the study. All inputs to the system related to both energy consumption (fuel and electrical power) and natural resources (water) were also included. The study also took into consideration the system outputs, such as the emissions into the atmosphere and into water from all the processes as well as the impact produced by the solid waste that is generated (both municipal and hazardous solid waste) and its transport to the corresponding management facility. The treatment undergone by each kind of waste at the management facilities lies beyond the scope of this study.

2.3 Quality of the data

The indicators employed to specify the quality of the data throughout this study are those shown in **Table 1**.

2.4 Definition of the functional unit

The functional unit (F.U.) 1 ton of clay as produced and sold. Transport to the customer and the part that is not sold (overburden) were also taken into account in the unit processes defined for the purposes of this research.

3 Life Cycle Inventory

The Life Cycle Inventory (LCI) was performed following all the steps set out in the ISO 14041 (1998) standard, as well as the examples and formats detailed in the ISO/TS 14048 (2002) and ISO/TR 14049 (2000) standards.

Field data supplied by the company, WBB-Spain, for the year 2004 was used to gather information about the inputs (i.e. materials, water and energy resources) and outputs (i.e. airborne and waterborne emissions and solid waste) for each of the 16 unit processes the overall process of mining, treat-

Table 1: Quality indicators

Requirement	Quality indicator
Age of data	All the data used in this study refer to the period January–December 2004
Level of aggregation	A single source of data (Moró Mine), although the study can be extended to other similar locations
Source of information	All data were provided directly by the company or taken from the following commercial databases: Buwal 250, Idemat 96, IVAM LCA Data and Pré Consultants database
Method of data collection	All data were measured directly in the processes under study (except for those taken from databases)
Allocation	The criteria applied were based on the production of clay and, above all, on the consumption of fuel by the machinery assigned to each process (the allocations that were made are detailed in section 3)

ment and marketing clay was divided into. These overall data were assigned to the functional unit by applying the following rules of allocation:

– The consumptions (fuel and maintenance materials) and emissions of the mining machinery were assigned in proportion to the time spent on each process.
– Maintenance and cleaning equipment was assigned to office and laboratory processes according to the estimated surface area of these facilities.
– 50% of the consumptions/emissions of the commercial vehicles was assigned to the ancillary process of offices, while the other 50% was split evenly between the phases of mining raw materials and production.
– The waste from vehicle maintenance was assigned in proportion to the fuel consumption of the machinery involved in each process. Oil waste from maintenance of the machinery was assigned in proportion to the amount of oil consumed by the machinery.
– Municipal solid waste was shared out in proportion to the estimated surface area of the offices and laboratory.
– Consumption of electrical power was assigned according to an estimate provided by the company.

After completing the allocations to the functional unit, each of the 16 unit processes that go to make up the process of mining, treating and marketing clays were then modelled as new sub-processes using SimaPro (Pre 2001) software. As an example **Table 2** shows the life cycle inventory record for process 1, that is, removal of the layer of vegetation and preparation of approaches. Similar records were produced for the other unit processes.

Table 3 reveals the source of the inventory data for each of the system inputs and **Table 4** displays the percentages of primary energies taken into account for the production of electrical power (percentages for Spain for the year 2004, REE [2004]).

Table 3: Source of the inventory data for each of the system inputs

LCI data	Database
Fuel	BUWAL 250
Filters	IVAM LCA
Cloths and absorbents	IDEMAT 96
Scrap input	BUWAL 250
ANFO ('Nagolita')	IVAM LCA
Antifreeze	IVAM LCA
Surface active agents	Pre4 Database
Acetone	IVAM LCA
N_2	IVAM LCA
Metal packaging	BUWAL 250
Aerosols	BUWAL 250
Packaging explosives	BUWAL 250
Riogel	IVAM LCA
Dissolvent	IVAM LCA
HCl	IVAM LCA
O_2	BUWAL 250

Table 4: Percentages of primary energies taken into consideration for the production of electrical power (REE 2004)

Origin	%
Hydroelectric	14.40
Nuclear	30.72
Coal + anthracite	18.82
Lignite	11.81
Imported coal	6.39
Natural gas	15.94
Fuel-oil	1.92

4 Life Cycle Impact Assessment

Once each of the aforementioned sub-processes had been modelled with the SimaPro (Pre 2001) software application, the next stage was to carry out the assessment of the impact

Table 2: Process 1: Removal of the layer of vegetation and preparation of approaches

	Category	Material	Amount/F.U.	Source of data
INPUTS	Fuel A	Industrial 'low tax' diesel	0.0015 litres	Straight from the company: fuel for grader
	Fuel B	Standard diesel	0.00068 litres	Straight from the company: allocation of commercial vehicles
	Minor raw materials	Filters	1.77×10^{-6} kg	Estimate: waste statement
		Metal packaging	1.79×10^{-6} kg	Estimate: waste statement
		Cloths and absorbents	1.02×10^{-6} kg	Estimate: waste statement
		Aerosols	8.54×10^{-9} unit	Estimate: waste statement
		Scrap input	2.25×10^{-5} kg	Estimate: waste statement
	Vehicle maintenance	Grease	1.28×10^{-6} kg	Straight from the company: allocation by fuel consumption
		Antifreeze	6.83×10^{-7} litres	Straight from the company: allocation by fuel consumption
		Dissolvent	2.56×10^{-7} litres	Straight from the company: allocation by fuel consumption
OUTPUTS	Waste management	Filters used	1.77×10^{-6} kg	Straight from the company (see rules of allocation)
		Metal packaging	1.79×10^{-6} kg	
		Cloths and absorbents	1.02×10^{-6} kg	
		Polluted soils	8.97×10^{-7} kg	
		Aerosols	8.54×10^{-9} unit	
		Residues from hydrocarbons	1.25×10^{-5} m^3	
		Scrap	2.25×10^{-5} kg	

following the guidelines set out in the ISO 14042 (2000) standard. Results have been considered by impact categories (compulsory elements) and by impact assessment methods (optional elements).

4.1 Compulsory elements: Results by impact categories

The inventory data obtained in the previous stage were grouped according to five impact categories (global warming, ozone layer depletion, photochemical oxidation, acidification and eutrophication) according to the CML'2000 method (Guinée 2000). **Table 5** reports the overall indicator obtained for the whole process, while **Fig. 2** shows a graphic representation of the contribution made to each CML's impact category by each of the unit processes that the process of mining, treating and marketing clays was divided into.

Table 5: Absolute values by impact categories, according to CML'2000 (Guinée 2002)

Impact category	Total	Unit
Global warming	3.99	kg CO_2 eq.
Ozone layer depletion	2.88 x 10^{-6}	kg CFC-11 eq.
Photochemical oxidation	8.18 x$\cdot 10^{-4}$	kg C_2H_2 eq.
Acidification	4.12 x 10^{-2}	kg SO_2 eq.
Eutrophication	8.68 x 10^{-3}	kg PO_4^{3-} eq.

4.2 Optional elements: By impact assessment methods

Additionally, the inventory data have been normalised and weighted according three different methods for assessing impact: Eco-Indicator'95 (Goedkoop 1995), Eco-Indicator'99 (Goedkoop and Spriensma 2000) and EPS'2000 (Steen 1999a,b). As a result, a single indicator is obtained for the overall process and another for each of the 16 unit processes. Finally, and following the recommendations of the ISO 14042 (2000), a sensitivity analysis is conducted to evaluate the extent to which results are affected by the method that was applied.

The results of the environmental impact assessment (**Fig. 3**) are presented according to the contribution made to that impact by each of the three phases the life cycle of the pro-

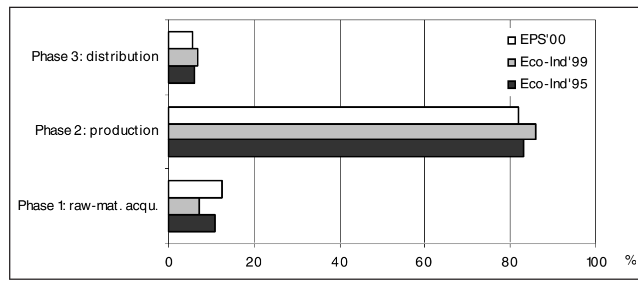


Fig. 3: Contribution made to impact by each phase of the life cycle, depending on the method of impact assessment employed

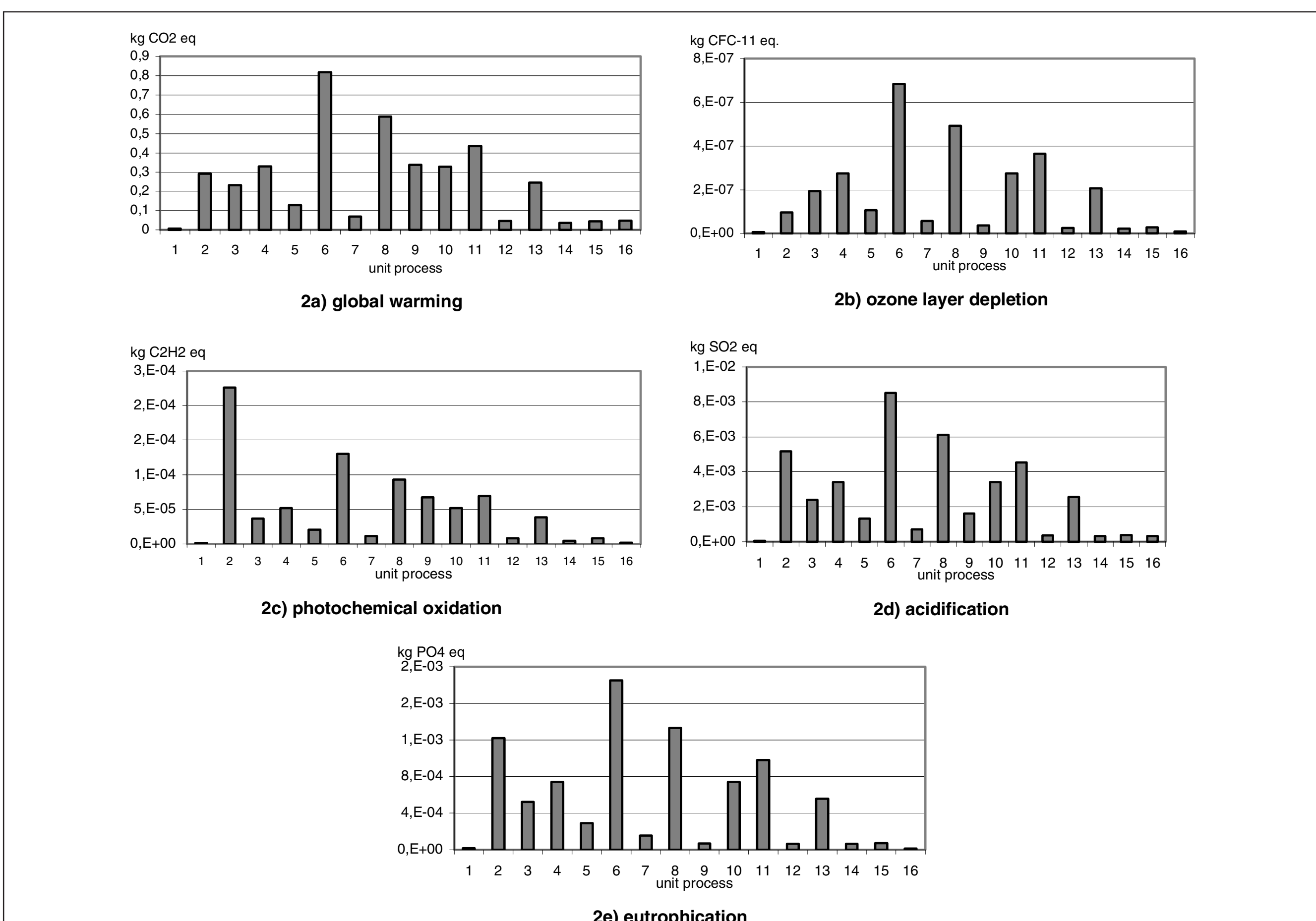


Fig. 2: Contribution made by each unit process to each impact category

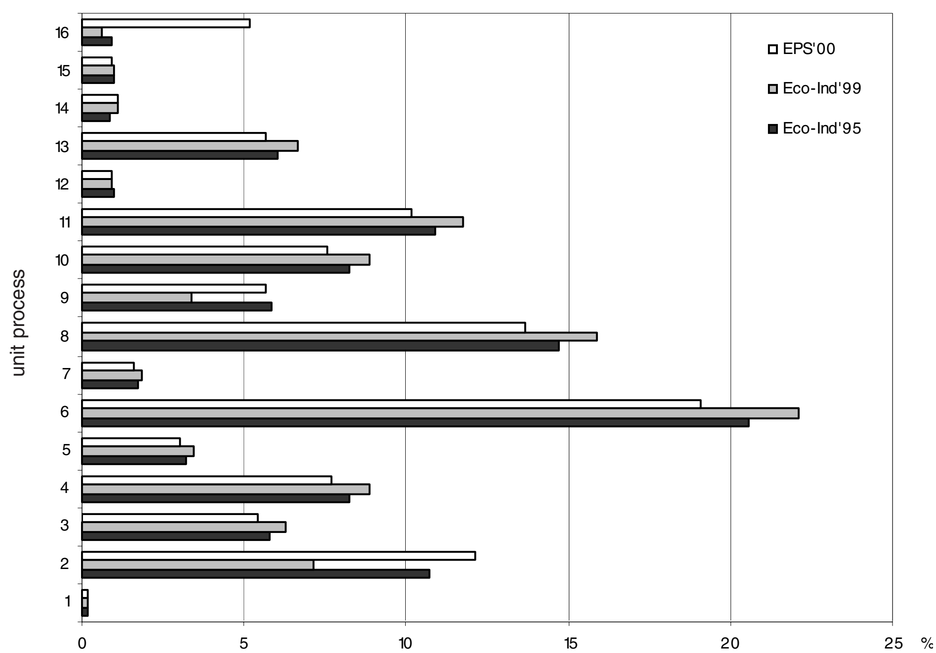


Fig. 4: Contribution made to impact by each of the 16 unit processes, depending on the method of impact assessment employed

duction of clays was divided into (mining of raw materials, production and distribution).

It can be seen that, for the three methods under study, the phase with the greatest impact is that of production, while the impact resulting from the phases of mining raw materials and distribution are very similar. This can be explained by the number of processes included in each phase, which has a direct correlation with the consumptions and emissions that were analysed and which were mainly due to the fuel used by the mining machinery.

Fig. 4 shows the contribution to impact made by each of the 16 unit processes into which the process of mining, treating and marketing clays was divided for each of the three methods of impact assessment applied in this study.

It can be clearly observed that choosing one method of assessment or another does not have any important repercussions on the final results that are obtained. The two most similar methods are Eco-Indicator'95 and EPS 2000, while a slight deviation is seen in the case of Eco-Indicator'99. This difference becomes notable in processes 2 and 9 with respect to numbers 6, 8, 11 and 10. In these last cases the value awarded by the Eco-Indicator'99 exceeds by far that of the other two methods and the reverse is true for the first two processes. The reason for this is that the characterisation factors used in the Eco-Indicator'99 method grant more specific weight to the consumption and the emissions of fossil fuels.

5 Discussion

Although an eco-label for hard floor-coverings exists (Commission Decision 2002, Baldo et al. 2002), the eco-label for red clay for use in the ceramic industry has still to be developed. Nevertheless, the construction sector has recently set its aim on obtaining the Environmental Product Declaration (ISO/TR 14025 2000) for the different materials involved in the different stages of the life cycle of products, as it is seen as being a useful tool to aid customers in decision-making (Erlandsson et al. 2005). More particularly, product-category rules (PCR) for preparing an Environmental Product Declaration (EPD) for ceramic tiles, expanded clay, concrete, cement or clay construction products such as bricks, tiles and roof tiles are currently being developed as part of the EU Life Environment funded INTEND project.

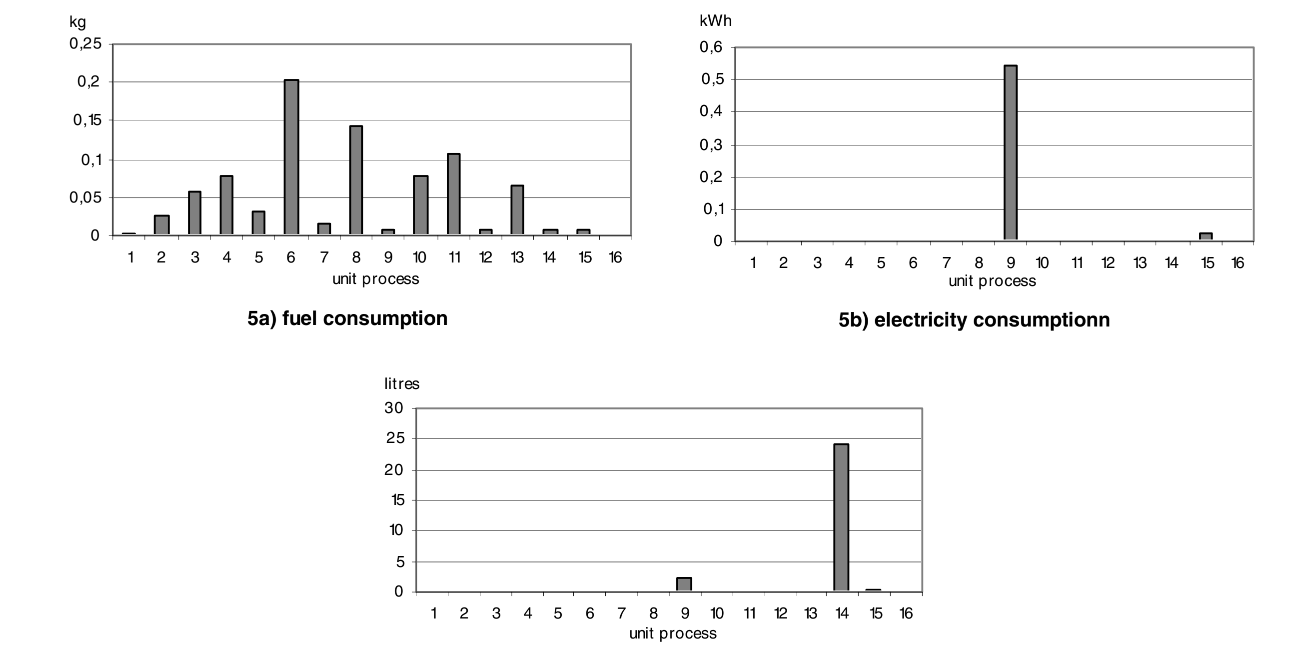
From this EPD perspective, it would be desirable to define other environmental parameters in addition to the impact categories for pollutant emissions (reported in Table 5) that are traditionally considered in LCA studies. In this paper, environmental parameters for resource use, waste generation and land use and rehabilitation have been defined.

Resource use has been classified into fuel consumption, electricity consumption and water consumption. **Table 6** reports the overall values obtained for the whole process, while **Fig. 5** shows a graphic representation of the contribution made by each of the unit processes that the process of mining, treating and marketing clays was divided into.

Waste generation has been divided into two categories, as shown in **Table 7**. The 'Dangerous wastes' group contains fuel left over from cleaning fuel tanks, filters, contaminated

Table 6:. Absolute values for resource use

Additional parameters	Total	Unit
Fuel consumption	0.84	kg
Electricity consumption	0.57	kWh
Water consumption	26.66	litres



5a) fuel consumption

5b) electricity consumptionn

5c) water consumption

Fig. 5: Contribution made by each unit process to resource use category

Table 7:. Absolute values for waste generation

Additional parameters	Total	Unit
Dangerous waste	17.06	kg
Non-dangerous waste	0.03	kg

metallic containers, contaminated textiles, etc., while the 'non-dangerous wastes' group is made up of scrap metal, plastics and urban solid wastes. The distribution over the unit processes can be seen in **Fig. 6**.

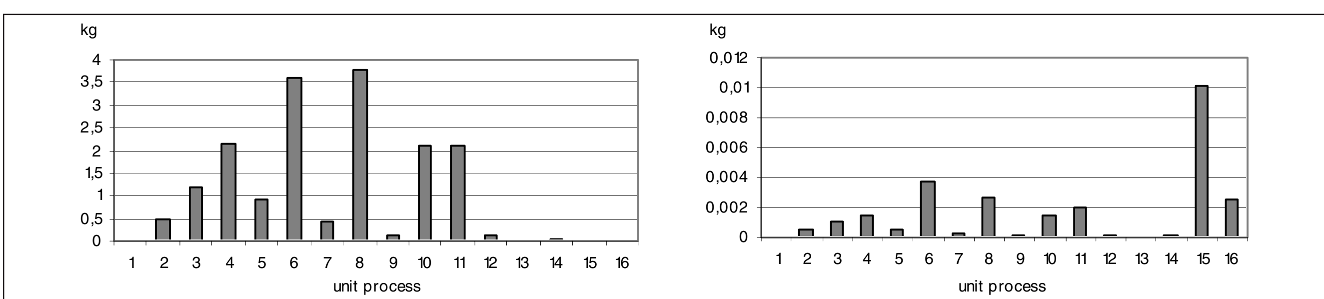
Taking into account the characteristics of the product being analysed, additional parameters related to the extraction of the resource during the mining process should be considered. Land use and its later restoration are an increasingly important component of sustainability evaluations in mining processes. However, these impacts are not usually incorporated into LCA studies either as impact categories or in the impact assessment methods. Stewart (2001) indicated that the impact categories traditionally included in LCA needed to be reviewed since they are unable to reflect the performance of the mining industry and additional impact categories should be investigated. In this respect, numerous performance metrics have been developed to meet this need (Lindeijer 2000, Leideijer et al. 2001, Spitzley and Tolle 2004). However, the selection of appropriate metrics remains an ongoing challenge.

Bearing in mind some of the ecological criteria for raw material extraction established in the eco-label for hard floorcoverings, three criteria were selected to quantify the environmental impact due to land use and land rehabilitation:

- Natural resource appreciation (%), calculated as the ratio between the commercialised material and the total volume extracted yearly:

$$\frac{m^3 \text{ commercial clay}}{m^3 \text{ extracted material (clay + overburden)l}} x100$$

- Land use efficiency (m^3/m^2), calculated as the ratio between the total amount of commercial clay and the used area.



6a) dangerous waste

6b) non-dangerous waste

Fig. 6: Contribution made by each unit process to waste generation category

$$\frac{m^3 \text{ commercial clay}}{m^2 \text{ used area}}$$

- Degree of rehabilitation (%), calculated as the ratio between the rehabilitated area and the area that has been used:

$$\frac{m^2 \text{ rehabilitated area}}{m^2 \text{ used area}} x100$$

The application of these parameters to the case study is reported in **Table 8**.

Table 8: Absolute values for land use and rehabilitation

Impact category	Total	Unit
Natural resource appreciation	59.9	%
Land use efficiency	1.38	m^3/m^2
Rehabilitation degree	1.08	%

As well as their value as additional criteria for an EPD, these environmental parameters can also be used as criteria for a future labelling of red clay. The environmental profile defined for fuel consumption in Fig. 5a reproduces the profile obtained for pollution emissions (see Fig. 2). Thus, by taking into account the fuel consumption for the processes of excavation, transporting and loading the clay (processes 6, 8, 10 and 11), nearly 65% of the total fuel consumption is considered. The electricity used in the crushing process and the water used in the sprinkling process are the key factors for controlling the use of resources in terms of electricity and water consumption, respectively. Finally, land use impact can be defined by the two criteria described above, since they clearly quantify the efficiency of the process in terms of area and volume needed to obtain the commercialised clay. The degree of restoration can be used as a criterion to measure the amount of damaged vegetation that is rehabilitated.

6 Results and Conclusions

This paper reports the findings obtained after carrying out a cradle-to-gate study of the process of mining, processing and marketing clays for use as an input material in the ceramics industry. The following results and conclusions can be obtained from the analysis described above:

- From the impact categories related to pollution emissions: In general, all the impact categories that were considered for pollution emissions reflect a similar profile, in which the most notable points are the contribution made by processes 6 (excavation & loading the clay) and 8 (transporting the clay to feed the hopper of the crusher), followed by processes 11 (loading dumper trucks for delivery to customer) and 10 (loading & transport to stockpiles). On examining the values from the inventory, it can be seen that there is a clear correlation with fuel consumption (see Fig. 5a). If we conduct a more thorough analysis of the findings for each impact category taking into account the substances responsible for the most notable impacts in each case, it can be concluded that:
  - In the category 'global warming', the CO_2 emitted during the combustion of diesel is responsible for the profile that is observed, but two other greenhouse gases, N_2O and CH_4, also make a significant contribution. These greenhouse gases are to blame for the role played by process 2 (boring and blasting) and number 9 (crushing). In the first case these gases are due to emissions from the explosives used and in the second they are a result of the emissions that occur during the production of electrical energy.
  - In the category 'ozone layer depletion' the profile of contributions is seen to be due only to the emissions from the combustion of diesel.
  - The category 'photochemical oxidation' is the one that displays the greatest variation in the profile of contributions made by the processes. Process 2 stands out above the others because of the emissions of NO_x from the explosives, since the main component of the explosives that are used is ammonium nitrate, which has powerful photochemical oxidising properties. The substances responsible for the impact of process 9 are the SO_x given off during the production of the electrical energy used by the crusher, while in the other processes the impact is due to CO (a gas produced during the combustion of diesel).
  - As far as 'acidification' is concerned, in this case the characteristic pattern due to NO_x and SO_x emissions from the combustion of fossil fuels can be observed. SO_x is responsible for the impact produced by the processes of boring and blasting (due to the explosives) and crushing (owing to the production of electrical power).
  - The pattern seen in the category 'eutrophication' is due to the NO_x given off during the combustion of diesel and, in the case of process 2, this gas is emitted by the explosives that are used, which are composed mainly of ammonium nitrate.
- From additional impact categories related to resources use and waste generation: As cited above, fuel consumption faithfully reproduces the environmental profile of most of the impact categories related to pollution emissions (see Fig. 5a). Moreover, the production of dangerous waste is mostly due to the hydrocarbons left over from cleaning fuel tanks, together with waste oil, and the amounts generated are therefore proportional to fuel consumption. The efforts being made to improve the environmental behaviour of the process of mining, treating and marketing clays will have to involve reducing the amounts of fuel consumed in the processes of excavation and loading (processes 6, 8, 10 and 11). For the same reason, the amount of electricity consumed in the sprinkling process (process 9) should also be decreased. These parameters can be used as criteria for obtaining the eco-label for red clay in the future.
- From additional impact categories related to land use and degree of rehabilitation: Once the mine is no longer being worked, the whole area is to be rehabilitated with local flora to integrate it back into the surrounding landscape again. However, throughout the year 2004 the degree of rehabilitation carried out reached only 1.1%, a figure that needs to be improved by better synchronisation of the two processes (mining and rehabilitation).

- From impact assessment methods: The results obtained from applying the LCIA show that the processes that have the greatest effect on the environment are those that involve a higher degree of fuel consumption, whereas the environmental impacts produced by the consumption of minor raw materials, by elements used in vehicle maintenance and by the management of waste that is generated are all practically negligible.
  Fuel consumption is responsible for about 80% of the overall impact in all the processes involved in the production phase except for those that entail a considerable amount of electricity consumption, the most important of which is the crushing process. In this particular process it is now clear why there was a difference between the assessment methods in Fig. 4: in distributing the contribution that each data category makes to the overall impact, the Eco-Indicator'99 method grants more specific weight to fuel consumption than to electrical power consumption. This fact can be seen above all in process 9 (feeding the hopper and crushing) and is repeated in process 12 (conveyor belt) and in ancillary process 15 (offices), because they also give rise to a considerable rate of electrical energy consumption.
  It is important to remark that parameters related to the land use/restoration of the area or resource depletion have not been included in any of the three impact assessment methods applied.

Finally, it must be pointed out that the ceramic tile industry should take a step forward by promoting and marketing products with a reduced environmental impact. The availability of exhaustive life cycle inventories is the key that will enable this industry to incorporate LCA during product development. Although this study performs the LCI for the basic input material (clay), future studies should be conducted to complete an LCI for the remaining raw materials and processes employed by the industry, with the aim of developing a characteristic LCI database for the ceramic tile industry.

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